Long-term changes in a small, urban estuary

By: Michal Viskich

Supervisor: Charles L. Griffiths

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Department of Biological Sciences, University of Cape Town

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Abstract

The Diep River estuary is a small, urban estuary situated in the suburbs of Cape Town and has been subjected to long-term modifications and abuse that far exceeds that of most other estuaries around South Africa. Activities in the Diep River catchment, together with the intensive urban development in the areas adjacent to the estuary, have resulted in massive changes in biodiversity, altered flow and salinity regimes; causing a marked deterioration in water quality and a frightening increase in non-indigenous species introductions. Several studies have been undertaken at the Diep River estuary, however, they are out-dated and many changes have occurred within the last few decades. The aim of this study was to provide an up-to-date list of the fauna residing within the Diep River estuary, as well as to provide a synthesis of all the major physical, hydrological and faunistic changes that have occurred within and around the estuary, dating back to the late 1800s, whereas faunistic changes are described using information provided by several earlier surveys dating back to the early 1950s. Infauna, epifauna and salinity were taken at designated stations along Milnerton Lagoon. Prawn (*Callichirus kraussi)* counts were also made in order to determine current abundance and distribution. Results showed a substantial decline in sand prawn abundance with the estimated standing stock calculated at just over 12 million. Fauna collected were generally poor in abundance and were mainly limited to euryhaline, detritus feeders. Earlier surveys conducted in the 1950s recorded at least 49 infauna and epifauna species residing within Milnerton Lagoon, whereas in 1974, only 23 species were found. Similarly, 24 species were recorded in this study. The European shore hopper (*Orchestia gammarella)* was recorded as a new introduction within the system. Only five fish species were recorded in the summer period, including the highly invasive mosquito fish (*Gambusia affinis*), which was found in relatively high abundance within the lagoon. A regular monitoring of the infauna and epifauna populations for this system needs to be established, in order to obtain a clear picture of the faunistic distribution and changes occurring within this highly dynamic environment. Additionally, serious management protocols need to be established in order to prevent the further degradation of this important system.

Keywords: Diep River estuary, Milnerton Lagoon, alien introductions, invasive, *Orchestia gammarella, Gambusia affinis, Callichirus kraussi*

Introduction

Estuaries are among the most extensively modified and threatened aquatic environments as a result of anthropogenic activities (Blaber *et al.* 2000; McQuaid 2013). The main threats facing estuaries include dredging operations, residential development, bank and mouth stabilization and water abstraction while secondary threats include pollution and the introduction of non-native species (Blaber *et al.* 2000; Gutierrez *et al.* 2011).

The term estuary refers to a body of water which forms the interface or transition zone between fresh water and the marine environment (Jackson *et al.* 2011). This distinguishing feature makes estuaries highly vulnerable and sensitive to development (Jackson *et al.* 2011), with many cities and harbours deliberately located in and around them, resulting in numerous unforeseen and undesirable consequences (Gutierrez *et al.* 2011). Some of these consequences include soil erosion, siltation, altered mouth closure regimes, nutrient enrichment and ultimately habitat degradation coupled with human health issues (Blaber *et al.* 2000; Gutierrez *et al.* 2011).

Fortunately, in recent years estuaries have become increasingly recognised as highly important ecological habitats. Estuaries provide a wide range of ecologically important functions, for example they are used as a nursery area for juvenile fish; as roosting and feeding sites for migrant bird species and as functionally important biological filters-breaking down waste and detoxifying pollution (Jackson *et al.* 2011). However, with increasing development and urbanisation, coupled with the long history of abuse that most estuaries have been subjected to, it is almost impossible to reverse them to their “natural” occurring state.

The Diep River estuary (Cape Town, South Africa) is an excellent example of an estuary subjected to long-term modifications and abuse that far exceeds that of most other estuaries around South Africa (Clark 1998). The Diep River estuary, otherwise known as Milnerton Lagoon consists of a variety of habitats, ranging from artificial, deep-water lakes to shallow, seasonally inundated pans (Retief 2011). The vlei part of the estuary is considered as one of the most important areas for water-birds in the south-western Cape and has been ranked within the top 10% of all coastal wetlands in this region in terms of the number of birds present (Jackson *et al.* 2008; Retief 2011). Whereas, the lagoon region of the estuary represents 10% of the utilised nursery area for fish on the west coast (Jackson *et al.* 2008). Several juvenile fish species such as Cape stumpnose and white steenbras are entirely dependent on this estuary and others as a nursery site (Jackson *et al.* 2008).

In 1984, the Diep River estuary was officially recognized as a Nature Reserve (Jackson *et al.* 2008). Later, in 1993 the Rietvlei Wetland Reserve was established (Jackson *et al.* 2008). Since then there have been several management plans developed in order to guide the management activities of the estuary (Jackson *et al.* 2008). Despite these initiatives and the recognized ecological importance of the lagoon, development encroaching within the boundaries of the estuary still continues today (Jackson *et al.* 2008; Jackson *et al.* 2011). The hydrodynamics of the system has been altered, water quality is increasingly becoming a public health concern and several non-native species have invaded the entire area (Jackson *et al.* 2008).

Several earlier studies have been undertaken on the Diep River estuary. A synopsis of all the available information has been compiled by Grindley and Dudley (1988). No published scientific information on the Diep River estuary is available before the 1950s, with Millard and Scott (1954) producing the first comprehensive study of the estuarine system. Since then, Weil (1974) (unpublished) performed an ecological survey of the estuary, following the methods done by Millard and Scott (1954). Du Toit (1982) (unpublished) and Bell (1976) (unpublished) also performed further ecological surveys of the estuary. However, these reports are out-dated and many changes have occurred in and around the Diep River estuary within the last few decades. Grindley and Dudley (1988) stress the need for a recent, comprehensive study of the Diep River system in order to be able to effectively manage this rapidly changing habitat.

The main aim of this study is therefore to provide an up-to-date list of the fauna residing within the Diep River estuary. The secondary aim is to provide a synthesis of all the major physical, hydrological and faunistic changes that have occurred within and around the estuary, using the information provided by Millard and Scott (1954), Weil (1974) and Clark (1998). Histological photos and maps will also be used to provide a visual effect of the long-term changes that have occurred at the estuary. From this study we hope to provide a framework for future studies to work from, as well as demonstrate the detrimental effects that an estuary can undergo if not properly managed.

Materials and methods

Study site

The Diep River estuary is situated approximately 5 km north of the city of Cape Town (Western Cape, South Africa) ($33^0 54^{'}$S; $18^0 28^{'}$E) (Taljaard *et al.* 1992). The estuary extends from the Diep River mouth up to Blaauberg Road Bridge and covers an area of approximately 900 ha (Retief 2011) (Fig 1). The estuary is divided up into two distinct regions – Milnerton Lagoon and Rietvlei. For this study we only focused our efforts on the Milnerton Lagoon section of the estuary, which extends from the mouth up to Otto du Plessis Drive (Fig 1).

Milnerton Lagoon is a relatively small (maximum 150 m width), shallow (maximum 3 m depth) estuary with an “artificially” shaped flow channel of rectangular shape (Clark 1998; Botes 2004). The lagoon is bordered by a road, a golf course and the Woodbridge Island residential development (Jackson *et al.* 2008) (Fig 2). Earlier studies indicate that the mouth seasonally closed during the dry summer months (November to March) and opened during the wet winter period (June to August) (Millard and Scott 1954; Weil 1974; Grindley and Dudley 1988). This phenomenon resulted in hyper-saline conditions and a reversed salinity gradient during the summer period, where certain parts of the estuary resembled salt-pans (Millard and Scott 1954; Botes 2004). What is interesting to note is that the salt content in the estuary is not only derived from the seawater intrusion at the mouth, but also from the river water (Millard and Scott 1954). The river water is said to be relatively alkaline and high in salt derived from the Malmesbury shales of the catchment area (Millard and Scott 1954; Retief 2011). However, additional salt is not the only substance washed into the estuary from the Diep River catchment area.

The Diep River catchment resides within the south-western Cape, covering an area of approximately 1125 km^2 and consists mainly of industrial, agricultural and residential (formal and informal) areas (Taljaard *et al.* 1992; Clark 1998; Paulse *et al.* 2009). A large fertilizer factory, petroleum refinery and Milnerton sewage works are situated next to Rietvlei (Taljaard e*t al.* 1992). Freshwater flow into Milnerton Lagoon comes from a variety of sources. One of the main freshwater sources is from the Diep River, which flows into the north-eastern corner of the Rietvlei wetlands (Retief 2011). Another main freshwater source is a channel carrying treated effluent from the Potsdam Waste Water Treatment Works (WWTW), which is discharged along the boundary of Rietvlei wetlands (Retief 2011). Additional sources include flow from storm water drains along the eastern bank of the

Rietvlei wetlands and a natural channel flowing from the western side of Rietvlei (Retief 2011).

Experimental design and protocol

The data used for this study can be divided up into three types:

I. Physical and Structural changes

The major physical and structural changes that have occurred within and around the estuary are presented with the use of a table. Histological maps and photographs are presented, with an adjacent current photograph and/or map of the estuary system. Histological maps and photos were obtained from a variety of sources, including the Western Cape Archives and Records Service and the Special Collections library at the University of Cape Town, and were used in order to provide a visual effect of the long-term changes that have occurred at Milnerton Lagoon.

II. Changes in salinity

Salinity measurements were taken using a portable salinity meter during the late summer period (April) and at the end of winter (August) in order to capture seasonal changes. Measurements were taken towards the end of high tide at five observation stations (Table 1). The stations used by Millard and Scott (1954) and Weil (1974) were again selected in this study in order to determine how salinity changed from the 1950s. Millard and Scott (1954) determined the salt content at each of the stations by the use of chlorinity measurements, we therefore converted the given average surface chlorinities (in gm/ litre) to salinity (ppt) using the equation: salinity=1.806 x chlorinity (Lewis 1980). We realize that this conversion is only an approximation due to the varying proportion of different salts in the system; however, it proved sufficient for our studies purposes.

Table 1: Observation stations

Station number	Description
1	At the mouth
2	The old weir
3	Milnerton Bridge
4	Milnerton High School (directly opposite the sport fields)
5	At the end of Broad Road. This station marks the upper limit of the lagoon.

III. Faunistic changes

The faunistic components of the lagoon can be divided into two sections:

a. Infauna, epifauna and nekton

Line transects were undertaken in summer (April) and winter (August) to sample the infauna and epifauna of the lagoon. The five observation stations were again used as markers, to where we performed our line transects. At each station we collected four sediment samples, starting from the edge of the lagoon bank and ending at the centre of the lagoon. All sediment samples were put through a 1 mm sieve. A small plankton net was also used to collect a sample of organisms in the water column at each of the stations.

Only macroscopic animals were collected and damaged specimens were not included in the species list. Fully terrestrial species collected along the marginal edge were also excluded from the species list. All samples collected were sorted, identified and then stored in 70% alcohol. Specimens were collected in this way in order to make comparisons with the species lists compiled by Millard and Scott (1954) and Weil (1974).

Nekton samples were collected by the Department of Agriculture, Forestry and Fisheries (DAFF), to which they sampled at various points along the lagoon using a small seine net during the winter and summer period of 2014. DAFF were kind enough to share their available fish data, to aid us in our study. We again used this data to make comparisons with the species list compiled by Millard and Scott (1954) and Weil (1974).

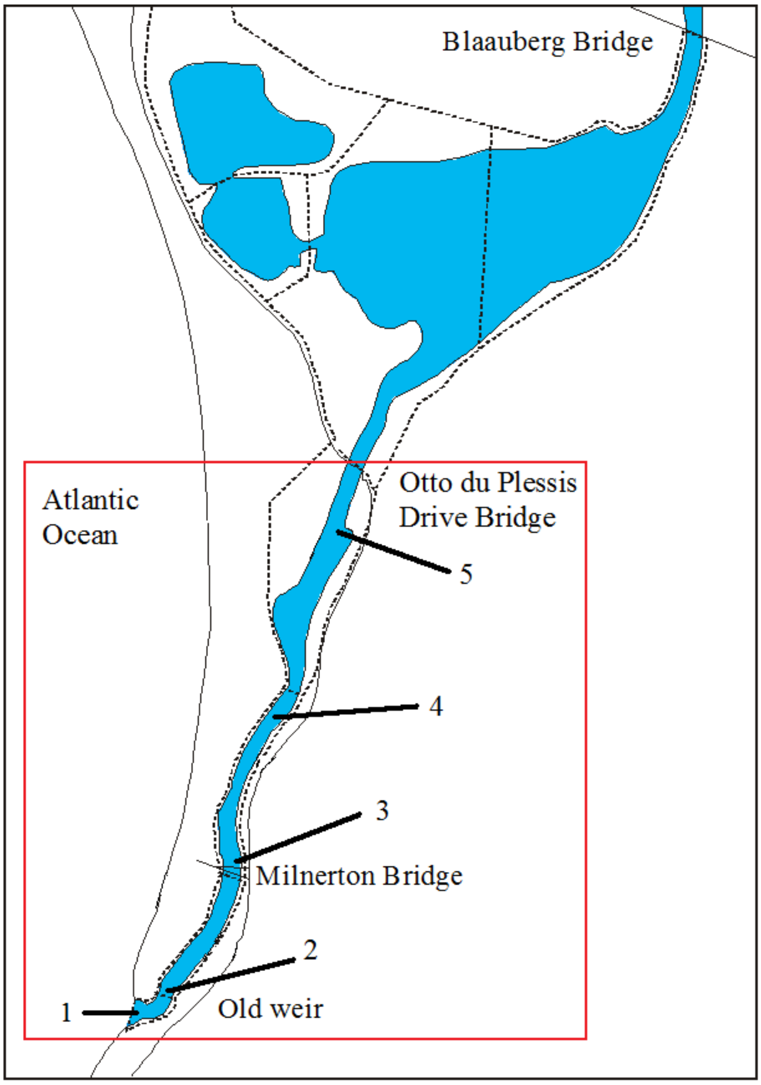

Fig 1: Map of the Diep River estuary showing the five observation stations and other features mentioned in the text (map adapted from Clark 1998). The highlighted section on the map shows the Milnerton Lagoon section of the estuary, to where data was collected.

b. Prawn counts

The sampling methods used to obtain an estimate of the abundance of sand prawns (*Callichirus kraussi*) at the lagoon are based on but differ slightly from those employed by Clark (1998). To start, the estuary was divided up into 100 m long blocks, extending from the low water mark at the mouth of the lagoon, up until Otto du Plessis Bridge. Sampling occurred within the summer period (April).

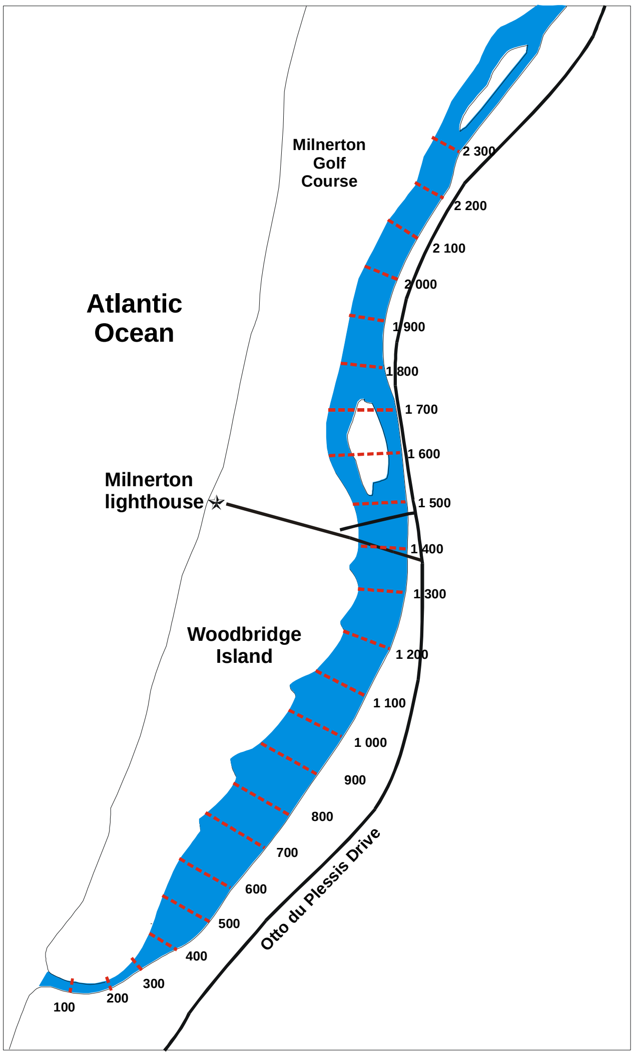

Fig 2: Map showing the lower part of the Diep River estuary and the approximate positions of the 100 m length blocks in which prawn counts were made (map taken from Clark 1998).

Within each of the 100 m length blocks, we randomly cast a 0.5 x 0.5 m sized quadrat 20 times, whilst moving in a zigzag fashion across the width of the lagoon. Within each quadrat we counted the number of burrows made by sand prawns. Several studies have shown that the ratio between the number of burrow entrances on the sediment surface with the number of animals buried below is between 1.0 and 1.1 holes per adult *Callichirus* (Wynberg and Branch 1991; Clark 1998). We could therefore gain an accurate estimate to the number of sand prawns present in the lagoon sediment by counting the number of burrow entrances using the average ratio of 1.05 to 1 (Clark 1998). Successive 100 m length blocks were surveyed up the length of the lagoon until no burrow openings were recorded in three successive blocks.

The width of the lagoon channel in each block was also measured in order to estimate the total number of sand prawns. This was done by taking the average number of burrows per quadrat divided by the area of the quadrat, multiplied by the area of the 100 m block.
The width of each block was measured until the limit of burrow occurrence as these did not extend into upper tidal levels.

Results

I. Physical and Structural changes

In the last 200 years, the Diep River estuary has been significantly modified. At the time of Van Riebeeck's arrival in the Cape in 1652, the Diep River had an extensive estuary system that entered the sea through two mouths, the current mouth situated slightly north of its current position and the other, further south at the present Salt/Black River mouth (Grindley and Dudley 1988; Clark 1998; Retief 2011). Since then, the removal of riparian vegetation, combined with poor agricultural practices, has resulted in the estuary becoming severely silted up, causing the estuary to become very shallow and have only one of its original mouths (Murray *et al.* 2009).

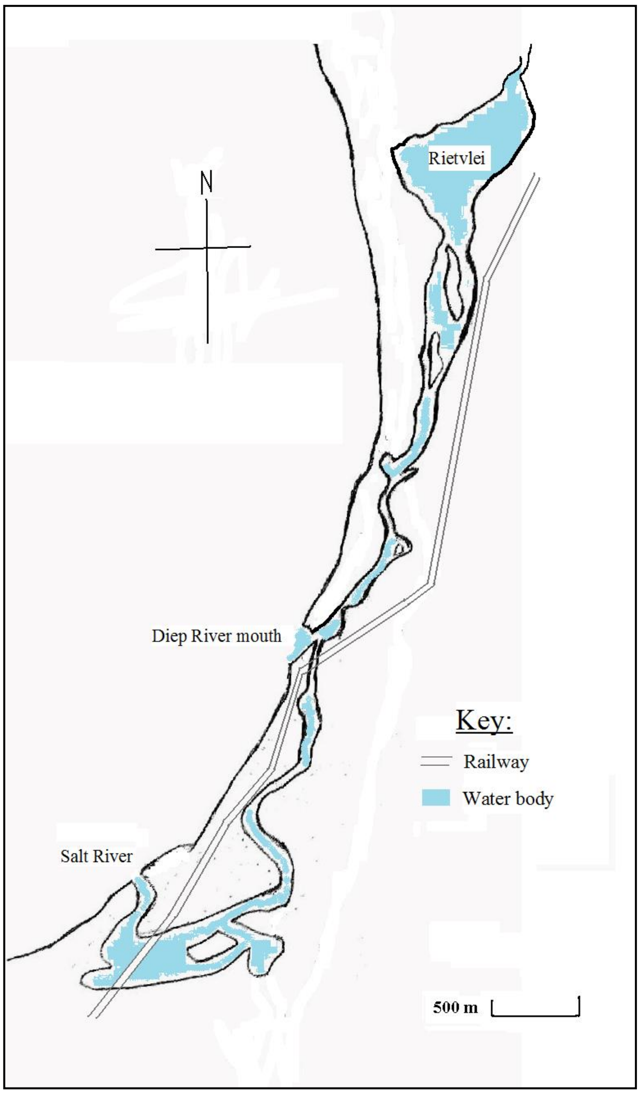

Fig. 3: Map of the Diep River estuary, 1846-1893. Map adapted from survey plans drawn by the Cape Town municipality in 1893 (Western Cape Archives and Records) and by Capt. Sir Edw. Belcher in 1846 (Grindley and Dudley 1988).

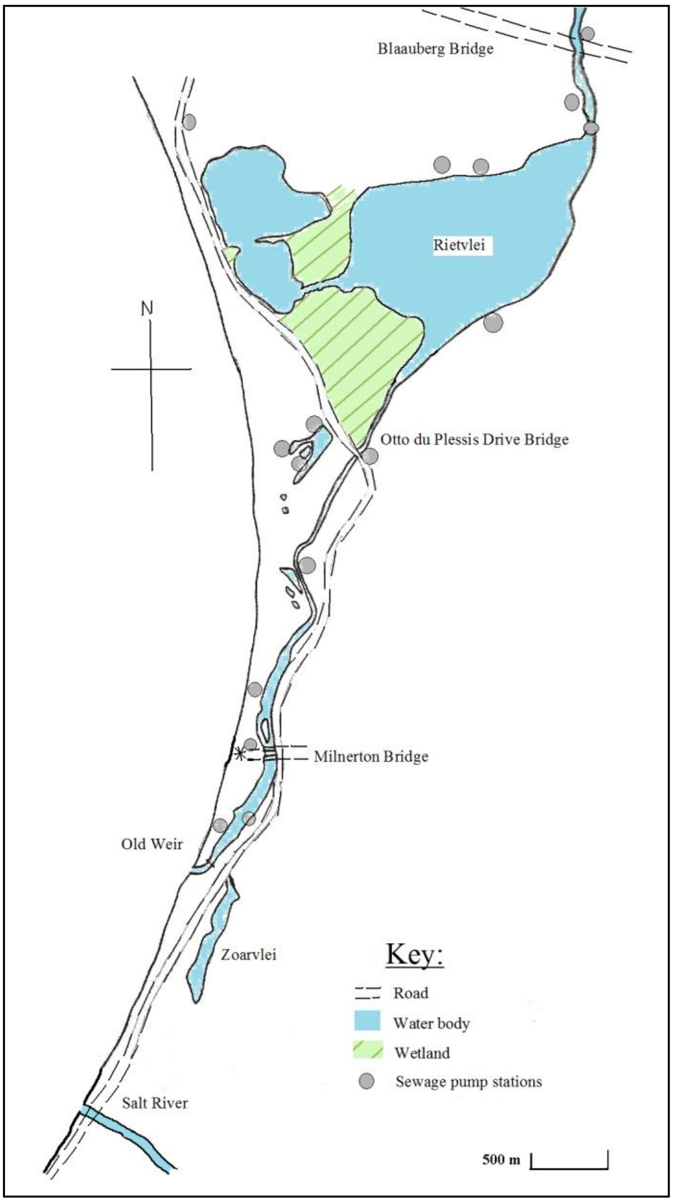

Fig. 4: Map of the Diep River Estuary, 2014. Map adapted from Clark (1998) and Google Earth (*source*: "Milnerton Lagoon." (33^{0}89$^{'}$S; 18^{0}48$^{'}$E). **Google Earth**. 26 September 2014).

Extensive silt deposition has further resulted in the substratum of most of Riet Vlei and the lagoon to become muddy (Jackson *et al.* 2011). The first direct evidence of large-scale siltation in the lagoon dates back to 1905, when parts of the lagoon were deepened for rowing regattas (Murray *et al.* 2009). By 1920 a sandbar had developed, closing off the lagoon mouth to the sea (Murray *et al.* 2009). To counteract these changes, a weir was build across the mouth in 1928, in order to increase water levels (Murray *et al.* 2009). The weir was subsequently demolished in 1942 during heavy floods (Murray *et al.* 2009; Jackson *et al.* 2008).

Historical records indicate that the Diep River mouth was almost permanently open to the sea (Grindley and Dudley 1988; Retief 2011). However, studies carried out in the 1950s and 1970s have indicated that the estuary mouth closed periodically during the summer months (Millard and Scott 1954; Weil 1974; Jackson *et al.* 2011). In 1960 the Potsdam Wastewater Treatment Works was built and then in 1991/92 a channel was constructed along the eastern boundary of the Rietvlei wetlands. Treated effluent from WWTW is discharged from this channel and into the lagoon. Since the excavation of this channel and the dredging activities that resulted in Woodbridge Island, the mouth has once again remained open (Murray *et al.* 2009; Jackson *et al.* 2008; Retief 2011). The discharge of sewage effluent into the system has also resulted in various other consequences, such as a massive drop in salinity in the system (discussed in greater detail below) (Jackson *et al.* 2011).

Fig. 5: Historic photograph of the wooden bridge. Few small buildings present in the background (Western Cape Archives and Records).

Fig. 6: Recent photograph of the old wooden bridge. Multiple, tall buildings present with a road running parallel to the lagoon. Photograph is taken from the golf course (*source*: Charles Griffiths).

Since the founding of Milnerton Estates Limited in 1897 and the railway line built in 1904, development and urbanisation began to peak (Grindley and Dudley 1988; Retief 2011). In 1904 a wooden bridge was built across the lagoon, to enable the British to gain access to the coastline near Milnerton in order to defend it against potential invaders (Murray *et al.* 2009). In 1985 a new concrete bridge was built next to the old wooden bridge when the Woodbridge Island Township was developed (Murray *et al.* 2009). Two other bridges have been built over the Milnerton Lagoon; Blaauberg Road Bridge demarcates the upper limit of the estuary while Otto du Plessis Drive Bridge, built in 1961, separates Rietvlei from the lagoon section of the estuary (Clark 1998; Murray *et al.* 2009). With increasing development pressure came the dredging of the north-west part of Rietvlei to a depth of 9 m in 1973, and then in 1985, the area below the wooden bridge was extensively dredged to provide sand for the Woodbridge Island Development (Jackson *et al*. 2008).

Urbanisation of the areas surrounding Rietvlei and the Milnerton Lagoon continued in conjunction with these developments. The land adjacent to the estuary is heavily developed with industrial and residential areas. The western bank of the estuary is bordered by the Milnerton Golf Course, the Woodbridge Island and residential developments, while the northern banks are bordered by the Theo Marais Sports ground, a fertiliser factory (Kynoch), Caltex Oil Refinery (Chevron) and the Milnerton Waste Water Treatment Works (Clark 1998; Retief 2011). Other industrial developments in the area include the Montague Gardens and Killarney Gardens industrial areas (Retief 2011). Storm water from residential areas enters the estuary via a number of drains, whereas the storm water from Chevron is discharged above the sewage works, while that from the Montagu Gardens enters the estuary near the Theo Marais Park (Clark 1998; Retief 2011). The estuary as you will find it today is a confined channel, stabilised by road embankments and various bridges, however, this estuary is still a highly important ecological gem within the Western Cape Province, represented as one of the last functioning wetlands in the south-western Cape (Clark 1998). The estuary is also recognised as an important recreational site, supporting fishing, bait collecting and a range of water sporting activities (Clark 1998; Retief 2011).

Fig. 7: **Left**: Historic photograph taken at the mouth of the lagoon, showing the demolished weir (Western Cape Archives and Records). **Right**: Recent photograph taken at the mouth of the lagoon. Multiple residential apartments with hardened, concrete embankments present along the lagoon mouth. Washed-up litter shown in the foreground (*source*: Charles Griffiths).

Table 2: Timeline of events that have occurred in and around the Diep River estuary

Date	Description
1899-1904	Wooden bridge built across Milnerton Lagoon.
1904	Railway line built.
1905	Sections of Milnerton Lagoon dredged.
1928	Weir built across the mouth of Diep River.
1929	Zonnekus-first house built on Woodbridge Island.
1942	Weir demolished.
1960	Potsdam Wastewater Treatment Works built. Effluent discharged into Diep River.
1961	Otto du Plessis Drive bridge build across Diep River, separating Riet Vlei and Milnerton Lagoon.
1973	Rietvlei dredged to a depth of 9 m to provide fill for construction in the Port of Cape Town.
1974	Lagoon again dredged for the Woodbridge Island development.
1985	New, concrete bridge built across lagoon, replacing the old wooden bridge. The area below the wooden bridge is dredged to provide fill for the Woodbridge Island Housing Development.
1991/92	Treated effluent discharged from Potsdam WWTW channelled along the eastern boundary of Rietvlei.
2004	Upgrade and expansion of Potsdam WWTW.

II. Changes in salinity

Since the establishment of the effluent channel along the east bank of Rietvlei in 1991/92, the estuary has become increasingly fresh water dominated; this is clearly shown by comparing the summer salinities at Otto du Plessis Bridge in 1954 (recorded at 204 ppt), 1974 (recorded at 80 ppt) and again in 2014 (recorded at 0 ppt) (Figure 8). Historically, the mouth would close periodically during the summer months; with the river effectively drying up. Combined with high evaporation rates, a reverse salinity gradient would then be established, with hypersaline conditions being experienced at the vlei area of the estuary-near Otto du Plessis Bridge (Millard and Scott 1954; Weil 1974; Jackson *et al.* 2011). This phenomenon is clearly illustrated by the 1954 and 1974 data in Figure 8.

More recently, the discharge of sewage effluent into the estuary has maintained relatively high flow levels, which have resulted in the mouth staying permanently open (Jackson *et al.* 2011). This has brought on some major consequences, notably, a major drop in salinity, compared to the salinity measured in 1954 and 1974 at the lagoon

(Figure 8). In 2014, this salinity drop is even more pronounced with roughly the same salinity values being found at each of the stations for both summer and winter (Figure 8). In summer the flow is made up predominantly of the effluent from the Potsdam WWTW (Jackson *et al.* 2011).

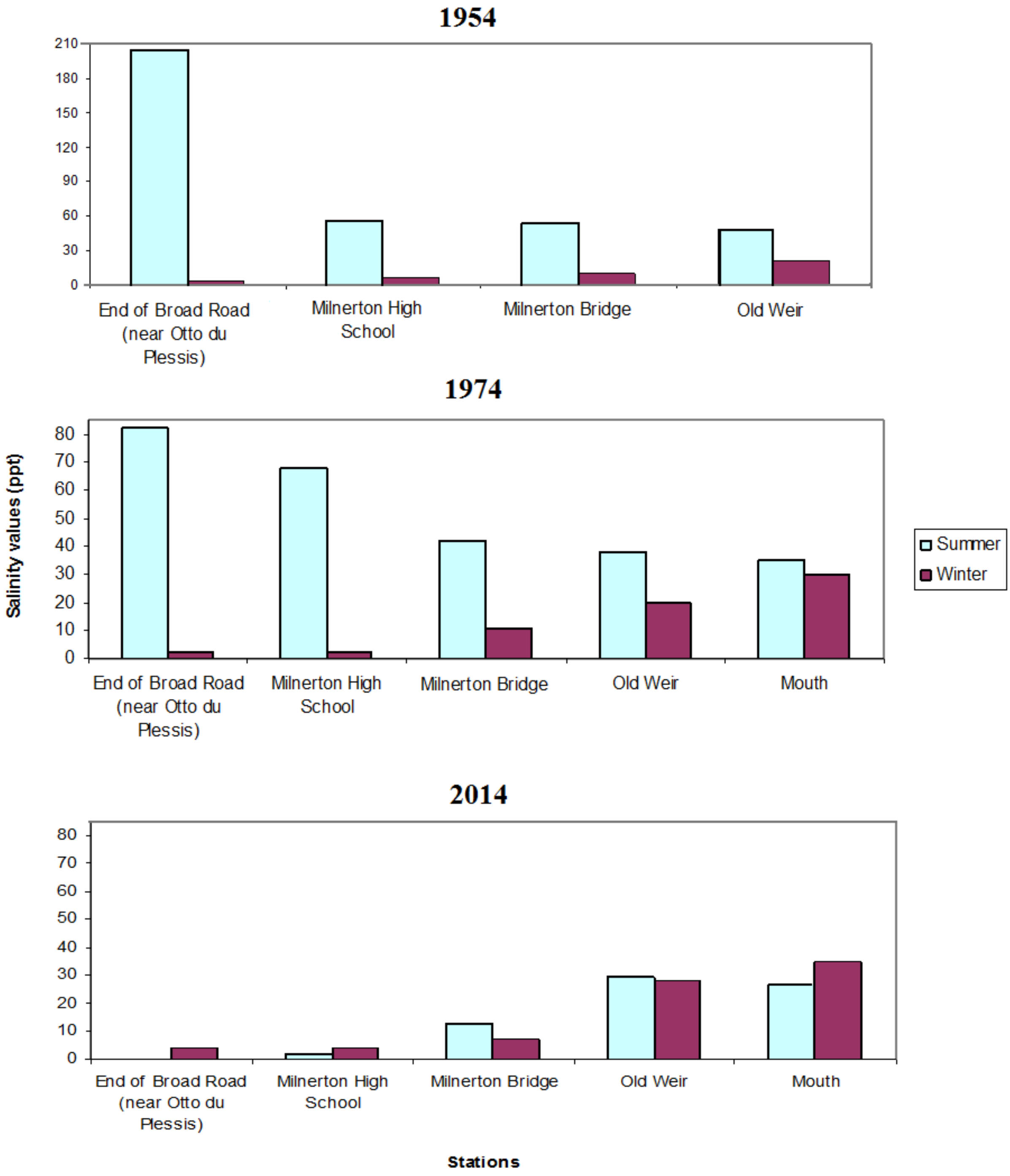

Fig. 8: Salinity measurements taken at the five observation stations during the winter and summer period at Milnerton Lagoon, in 1954 (Millard and Scott), 1974 (Weil 1974) and 2014 (this study).

III. Faunistic changes

a. Infauna, epifauna

The most noticeable changes that have occurred since the study done by Millard and Scott (1954) and Weil (1974); is the richness and diversity of species found residing within Milnerton Lagoon. Millard and Scott (1954) report finding gastropods, bivalves and even bryozoans within the lagoon (Table 3). A larger diversity and abundance of polychaetes, isopods and coleopteran species were also found, as compared to the tiny abundances and low number of species recorded within the lagoon today (Table 3). Since Weil (1974) it was clear that the infauna and epifauna within the lagoon had already begun to change for the worse. Weil (1974) frequently mentioned the fauna as being limited mainly to euryhaline, detritus feeders, which agrees with what was found in our study.

All three studies observed a noticeable blackening of the subsurface sediment over the majority of the estuary, accompanied by the smell of hydrogen sulfide (H_2S) and almost complete absence of burrowing organisms (Millard and Scott 1954; Weil 1974). Most of the invertebrates collected during this study were found living in sediments along the banks of the lagoon or among the aquatic vegetation. Weil (1974) found similar results, whereby he suggests that the oxygen concentration may be the limiting factor, controlling faunal distribution along the length of the lagoon and from the centre to the lagoon banks.

Across all three studies, the species collected during the summer period were found to be quite plentiful (Table 3); although overall the lagoon is lacking in terms of species richness. Only 24 species were recorded in 2014, compared to 48 species having been recorded in 1954 (Table 3). The most abundant species recorded in 2014 include *Ceratonereis erythraeensis*, *Hymenosoma orbiculare*, *Ishnura senegalensis* nymphs, *Sigara meridionalis* and Chironomidae larvae (Table 3). Species were also most abundant from stations 3-5 during the summer period in 2014, although during winter, a higher abundance of species was recorded at the mouth of the estuary (Station 1) (Table 3). Majority of the species collected during the winter period were found at the mouth of the estuary, in the water column. The heavy winter rains seemed to have flushed fresh water species from stations 4 and 5, out into the estuary mouth. The water was also highly turbid and seabirds crowded the estuary mouth, picking out juvenile prawns and insects.

For the 2014 study it was found that *Scolepsis squamata* dominated at station 1 in the summer, with 10 individuals being recorded, in contrast, *Sigara meridionalis* dominated at station 1 in the winter, with 73 individuals being recorded. *Capitella capitata* and *Eurydice* *longicornis* dominated at station 2 for the summer period. The Nereid polychaete (*Ceratonereis erythraeensis*) was found in highest abundance at the Milnerton Bridge (station 3), with a total of 72 individuals recorded in the summer and winter period. *Ceratonereis erythraeensis* also dominated at station 4 in winter. In the summer, *Ishnura senegalensis* nymphs dominated at station 4 with 94 individuals recorded, whereas Chironomidae larvae dominated at station 5. Overall, across all three studies it is apparent that there is a much higher species richness and abundance during the summer period (April), as compared to the winter period (August) (Table 3).

Polychaetes make up 33% of the total species abundance collected at the lagoon for 2014 and they dominate within the centre of the lagoon. The Nereid polychaete (*Ceratonereis erythraeensis*) was found in relatively high abundance in 2014, although was not recorded as present in the lagoon by the previous two studies done by Millard and Scott (1954) and Weil (1974). The opportunistic polychaete- *Capitella capitata* was found in relatively high abundances in all three studies.

What is interesting to note is that the two species *Ceratonereis erythraeensis* and *Orchestria gammarella,* which were recorded from stations 3-5 in 2014, were not recorded as present in the lagoon by the previous two studies done by Millard and Scott (1954) and Weil (1974) (Table 3). *Euborellia annulipes* (ringlegged earwig) including a few other low abundance species were also recorded as new introductions within the lagoon (Table 3). Insects make up the majority of species residing within the lagoon (56%), and include mayfly nymphs, coleopteran beetles and fly larvae.

An important thing to note is that *Capitella capitata, Ficopomatus enigmatica, Melita zeylanica* and *Hymenosoma orbiculare* were recorded in relatively high abundances in all three studies (Table 3). Weil (1974) noted *Ficopomatus enigmatica* as the most successful colonizer within Milnerton Lagoon, recorded as highly abundant at stations 1 and 2, extending all the way until station 5 (Table 3). Millard and Scott (1954) also recorded this species as present from stations 3-4 (Table 3). *Melita zeylanica, Hymenosoma orbiculare* and *Ischnura senegalensis* nymphs were found in relatively high abundance in all three studies where *F. enigmatica* reefs were established (Table 3).

Table 3: Complete species list of all infauna and epifauna recorded at Milnerton Lagoon for this study (2014), Millard and Scott (1954) and Weil (1974). The total number of species recorded at each station (refer to Table 1), in winter and summer and the total number of species collected in each study is also presented. (√ = present; AB = abundant).

		This study 2014										Weil 1974										Millard and Scott 1954									
		Summer					Winter					Summer					Winter					Summer					Winter				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Plathelminthes													√	√	√	√										√					√
Nematoda													√	√	√	√		√					√	√	√	√					
Plumatellida	*Lophopodella capensis*																									√					√
Cheilostomata	*Membranipora sp.*																						√								
Mytiloida	*Mytilus meridionalis*																					√					√				
Ostreoida	*Ostrea sp.*																					√									
Gastropoda	*Helcion pruinosa*																					√									
Gastropoda	*Argobuccinum argus*																										√	√	√		
Gastropoda	Assiminea sp.																										√				
Gastropoda	*Tomichia ventricosa*																									√					
Gastropoda	*Bullia digitalis*																										√				
Sacoglossa	*Hermaeina sinusmensalis*																						√								
Gastropoda	*Bulinus tropicus*																									√					
Actiniaria	*Anthothoe stimpsoni*												√	√																	
Heteronemertea	*Lineus olivaceus*												√	√																	
Scolecida	*Capitella capitata*		√	√	√			√	√				AB	AB	AB	√		√	√				√	√				√	√		
Phyllodocida	*Ceratonereis erythraeensis*			AB	√				AB	AB	√																				
Canalipalpata	*Ficopomatus enigmatica*			√	√								AB	AB	√	√	AB	AB	√	√	√			√	√				√	√	
Spionida	*Scolepsis squamata*	√											√									√					√				
Spionida	*Prionospio sexoculata*																						√	√	√			√	√	√	
Eunicida	*Lumbrinereis tetraura*																					√									
Phyllodocida	*Nephthys capensis*																						√					√			
Sabellida	*Oridia parvula*																							√					√		
Oligochaeta								√			√													√					√		
Cladocera													√		√					√	√										
Ostracoda													√		√					√	√										
Copepoda													√		√					√	√										
Cirripedia	*Balanus algicola*																					√									
Sessilia	*Amphibalanus sp.*						√																								
Isopoda	*Eurydice longicornis*	√	√																				√	√	√			√	√	√	
Isopoda	*Exosphaeroma hylecoetes*																								√						
Isopoda	*Exosphaeroma varicolor*																					√	√								
Isopoda	*Paridotea ungulata*																						√								
Amphipoda	*Orchestia gammarella*			√	√	√			√		√																				
Amphipoda	*Melita zeylanica*			√	√								AB	AB	AB			√					√	√	√						
Amphipoda	*Afrochiltonia capensis*													AB	AB	√			√				√	√	√	√		√	√	√	
Decapoda	*Callichirus kraussi*						√						AB	√	√	√	√	√	√				AB	√				AB	√		
Decapoda	*Hymenosoma orbiculare*		√		AB								√	√	√								√	√	√			√	√	√	
Decapoda	*Palaemon pacificus*												AB	√	√								√	√	√			√	√	√	
Decapoda	*Cyclograpsus punctatus*																						√	√				√	√		
Ephemeroptera	Leptophlebiidae					√																									
Ephemeroptera	*Eristalis sp. (larvae)*														√																
Ephemeroptera	*Cloeon lacunosum*																							√	√	√			√		
Odonata	*Ishnura senegalensis (nymphs)*				AB	√																			√						
Dermaptera	*Euborellia annulipes*			√					√																						
Hemiptera	Belostomatidae					√																									
Hemiptera	*Micronecta scutellaris*			√	√																					√					
Hemiptera	*Sigara meridionalis*					√	AB																		√	√					
Hemiptera	Notonectidae						√																								
Hemiptera	*Enithares sp.*						√																								
Hemiptera	*Notonecta lactitans*																									√					
Hemiptera	*Plea piccanina*																													√	
Hemiptera	*Sigara sjostedti*														√	√				√	√										
Coleoptera	Hydrophilidae					√																									
Coleoptera	*Berosus spretus*														√	√				√	√				√	√			√	√	
Coleoptera	*Helophorus aethiops*																													√	
Coleoptera	*Helochares dilutus*																								√						
Coleoptera	*Hydrochus sp.*																								√	√					
Coleoptera	*Ochthebius extremus*																									√				√	
Coleoptera	*Rhantus peringueyi*																								√						
Coleoptera	*Bledius sp.*		√				√								√	√															
Coleoptera (larvae)								√																							
Coleoptera	*Pogonus lamprus*														√	√															
Coleoptera	*Berosus sp. (larvae)*														√																
Diptera	Culicidae																			AB	AB										
Diptera	*Fucellia capensis*	√																													
Diptera	*Tendipes sp.*												AB	AB	AB	√	√	√													
Diptera	*Chironomus sp.*																						√	√				√	√		
Diptera	Chironomidae (larvae & pupa)				√	AB	√																		√	√					
Diptera	Ephydridae																							√	√	√			√	√	√
Collembola																								√	√	√			√	√	√
Total number of species at each station		3	4	7	9	7	7	3	4	1	3	0	15	12	19	11	3	6	4	7	7	7	16	17	19	16	5	11	17	12	4
Total number of species in each season		18					13					22					13					43					27				
Total number of species in each study		24										23										48									

There are only five fish species recorded in the Diep River estuary for the summer period in 2014 (Table 4). The most abundant species found include firstly *Liza richardsonii* (harder), which is an opportunistic species, able to survive in both estuarine and marine environments (Jackson *et al.* 2008). Other abundant species include *Gilchristella aestrius* (estuarine round-herring) and *Gambusia affinis* (mosquito fish). *Gambusia affinis* is a highly invasive species and was found in relatively high abundance in the forth and fifth stations in this study. *Liza richardsonii*, *Tilapia sparmanii* and *Gambusia affinis* are recorded as new inhabitants within Milnerton Lagoon in recent years (Table 4).

There is a clear decline in species richness since the study carried out by Millard and Scott (1954), with a total of twelve species recorded by Millard and Scott (1954) during the summer and winter period (Table 4) and nine species recorded by Weil (1974). Millard and Scott (1954) report the thin lip grey mullet, white steenbras and white stumpnose as the most common fish found within the lagoon, whereas Weil (1974) found that the estuarine round-herring had the highest abundance within the lagoon.

Table 4: List of all the fish species recorded in the Diep River estuary in the summer and winter period of 2014, 1974 and 1954. Fish data were obtained from DAFF for the year 2014, while the data provided by Weil (1974) and Millard and Scott (1954) is also displayed for comparison. Species are grouped into their estuarine dependence categories (adapted from Jackson *et al.* 2008) (√ = present).

			DAFF and This study 2014										**Weil 1974**										**Millard and Scott 1954**									
			Summer					Winter					Summer					Winter					Summer					Winter				
			1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Estuarine residents that breed mostly in estuaries, never in the marine environment																							√			√		√			√	
Clupeidae	*Gilchristella aestrius*	Estuarine round-herring	1	80					108	2	8	1		20																		
Estuarine residents with marine and estuarine breeding populations																																
Atherinidae	*Atherina breviceps*	Cape silverside																			13	13	√			√		√				
Clinidae	*Clinus superciliosus*	Super klipfish																					√	√	√							
Gobiidae	*Caffrogobius nudiceps*	Barehead goby	13						2	2		5		4					1				√			√		√				
Mugilidae	*Liza ramada*	Thin lip grey mullet												15					3				√			√		√			√	
Gobiidae	*Psammogobius kysnaensis*	Knysna sandgoby												12					2				√			√		√			√	
Juveniles entirely dependent on estuaries as nursery areas																																
Mugilidae	*Mugil cephalus*	Flathead mullet												2									√			√		√			√	
Sparidae	*Lithognathus lithognathus*	White steenbras												6					1				√			√		√			√	
Sparidae	*Rhabdosargus tricuspidens*	Cape stumpnose																								√		√				
Juveniles occuring mainly in estuaries but also found at sea																																
Soleidae	*Heteromycterus capensis*	Cape sole																					√	√	√			√	√	√		
Juveniles occuring in estuaries but usually more abundant in the sea																																
Mugilidae	*Liza richardsonii*	Harder	190	290	610	125			2610	2100	11	96																				
Pomatomidae	*Pomatomus saltator*	Elf																					√			√						
Sparidae	*Rhabdosargus globiceps*	White stumpnose												4									√			√		√				
Freshwater species, sometimes found in estuaries																																
Galaxiidae	*Galaxias punctifer*	Dwarf galaxias																			8	8										
Introduced or translocated freshwater species, sometimes found in estuaries																																
Cichlidae	*Tilapia sparrmanii*	Banded tilapia			1							1																				
Poeciliidae	*Gambusia affinis*	Mosquito fish				30	18																									
Total number of species			5										7										12									

b. Prawn counts

In the study done by Clark (1998), the density of sand prawn (*Callichirus kraussi*) holes increased progressively upstream from the mouth, peaking at the 1100-1200 meter block with an abundance of just over $8x10^6$ prawns being recorded in that region of the lagoon (Fig. 2 and Fig. 9). Sand prawns were recorded up until 2.2 km from the mouth of the lagoon (Fig 9). Clark (1998) estimated the total standing stock at approximately 40 million and the level of prawn harvesting was considered sustainable. However, it was recommended that "all bait collecting be confined to the region between the mouth and 1000m upstream" (Clark 1998). This was done so to ensure that only half of the prawn population would be affected by the effects of prawn collecting (Clark 1998).

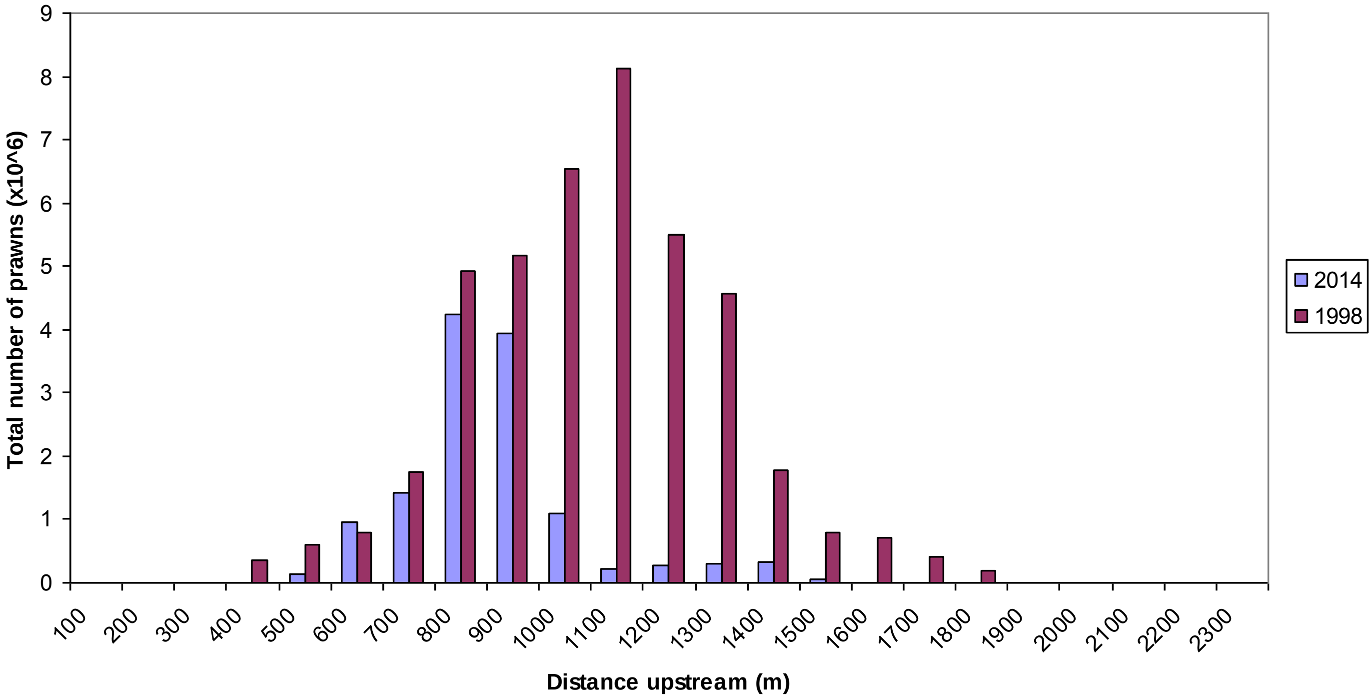

Fig. 9: Total number of sand prawns (*Callichirus kraussi*) per 100 m length block in the Diep River estuary (data for 1988 taken from Clark (1998)).

Since the study done by Clark (1998), the prawn population has declined substantially. From our study it was found that sand prawn abundance peaked at the 800-900 meter block, with just over $4x10^6$ prawns being recorded in that region of the lagoon (Fig. 10). Sand prawns were also only recorded up until 1.6 km from the mouth of the lagoon (Fig. 10). The estimated total standing stock of sand prawns in Milnerton Lagoon is calculated to be approximately 12.3 million. Additionally, it was determined that 93% of the total sand prawn population is currently vulnerable to bait collecting activities as all bait collecting activities are currently confined within the region between the mouth and 1000 m upstream, as recommend by Clark (1998) and seen from personal observation.

c. Alien invasive species

Two new introduced species have been recorded at the Diep River estuary in recent years; the amphipod *Orchestia gammarella*, and the fish *Gambusia affinis*. *Orchestia gammarella* (common name European shore hopper) commonly occurs along the drift-line (under rocks and on debris) and among dune vegetation (Mead *et al.* 2011). *Ficopomatus enigmatica* and *Gambusia affinis* are both highly invasive species recorded within the lagoon.

Table 5: List of all the cryptogenic and introduced species recorded at the Diep River estuary. Fish data was obtained from the Table Bay Nature Reserve and DAFF for the year 2014, while the data provided by Weil (1974) and Millard and Scott (1954) is also displayed for comparison (√ = present; AB = abundant).

	This study 2014										Weil 1974										Millard and Scott 1954									
	Summer					Winter					Summer					Winter					Summer					Winter				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Cryptogenic species																														
Capitella capitata		√	√	√			√	√				AB	AB	AB	√		√	√				√	√				√	√		
Melita zeylanica			√	√								AB	AB	AB			√					√	√	√						
Introduced species																														
Ficopomatus enigmatica			√	√								AB	AB	√	√	AB	AB	√	√	√			√	√				√	√	
Orchestia gammarella			√	√	√			√		√																				
Gambusia affinis			AB																											

Discussion

Physical and hydrological changes

Over the years, the Diep River estuary has been subjected to a long history of exploitation and abuse, rendering this system incapable of functioning as a completely natural system (Jackson *et al.* 2011). Dredging activities at the estuary have occurred on four separate occasions, in 1905, 1974 and 1985 sections of Milnerton Lagoon were dredged, while in 1973, a massive section of Rietvlei was dredged to a depth of 9 meters (refer to Table 2). Added to this, a total of four bridges have been built over Milnerton Lagoon with concrete road embankments stabilising most of the lower sections of the lagoon. The impacts of these changes have been augmented by the current use of the area for recreational sports, bait harvesting and fishing.

Dredging

Dredging of shallow-water estuaries has a profound effect on benthic infauna, microalgae and ultimately on fish species residing within the system (Ray 2005). Firstly, dredging involves the direct, physical removal of sediment which can cause massive implications for recruiting and establishing benthic infauna (Ray 2005). Dernie *et al.* (2003) showed that a difference of only 20 cm of sediment removed from a Welsh sand flat required 208 days for the infaunal community to be re-established. Additionally, increased depth contours created by dredging causes a reduction in ambient light at depth in the dredged area (Ray 2005). This negatively impacts on benthic microalgae, which are critical components of estuarine primary production, supporting many benthic invertebrates and fish species (Ray 2005).

Finally, the use of the dredged area may also result in many deleterious and unforeseen consequences for recruiting infauna and the surrounding environment (Ray 2005). Bait harvesting, fishing, swimming and canoeing form the bulk of disruptive recreational activities at Milnerton Lagoon (Clark 1998). Repeated physical disturbance of soft sediments has been shown to alter sediment chemistry, making it less attractive to recruiting infauna. Ultimately, routinely disturbed areas tend to have a less abundant and less diverse faunal community as compared to undisturbed habitats (Ray 2005).

Bridges

Bridges create an obstruction to the flow of watercourses, causing the river bed over which the bridge is located to become eroded (Kingston 2006). However, with development increasing and expanding within and around estuaries, other more detrimental consequences, arising from these constructions, have become apparent. With the development of concrete walls along the banks of the Diep River estuary and the construction of four bridges from 1904 till 1985 across the Milnerton Lagoon, large areas of soft sand and sediment were converted to hardened surfaces. McQuaid and Griffiths (2014) showed that hard surfaces may potentially facilitate the recruitment and/or expansion of exotic and invasive species within estuaries.

Water quality

With the increase in urbanisation around the Diep River estuary, a consequential, significant change in the volume and quality of water presently flows into the system (Jackson *et al.* 2011). Several effluent discharges are released into Rietvlei (Taljaard *et al.* 1992). The most important ones include the Potsdam Wastewater Treatment Works, storm water runoff from Caltex Oil Refinery (Chevron) as well as the large residential storm water discharge in the north-western section of Rietvlei (Taljaard *et al.* 1992; Murray *et al.* 2009; Jackson *et al.*

2008; Retief 2011). Taljaard *et al.* (1992) found that the estuary was relatively unpolluted with bacteria pollution in the lagoon noted as being minor. Trace metal concentrations were found to pose no toxicological threat to the biota within the system and were within maximum limits for water quality criteria (Taljaard *et al.* 1992). Since then, WWTW has subsequently upgraded and expanded, additionally a new sewage channel along the eastern boundary of the Rietvlei wetlands was constructed in 1991/92 (Murray *et al.* 2009; Jackson *et al.* 2008; Retief 2011). Various water quality studies have since been conducted at the estuary. Paulse *et al.* (2009) investigated microbial contamination at three sites along the Diep River. They found that at all three sites, the microbial counts exceeded the stipulated water quality limit guidelines (Paulse *et al.* 2009). Jackson *et al.* (2009) and Ayeni *et al.* (2010) went further to determine the extent of metal contamination along the lower Diep River. Both studies found the lower Diep River to be polluted with a variety of metals, with the concentrations of some of the metals exceeding established guidelines. Metal contamination has a detrimental effect on plants, microorganisms, human health and on overall ecosystem health (Ayeni *et al.* 2010). Jackson *et al.* (2011) suggests that the water in Milnerton Lagoon has been unsuitable for recreational contact since at least 2001.

Changes in Salinity

Historically, the mouth would close periodically during the summer months; the high evaporation rates would lead to hypersaline conditions and a reverse salinity gradient would be established (Retief 2011). Millard and Scott (1954) describe Rietvlei as “a series of extensive saline seasonal pans” whereby in late summer and autumn, Rietvlei was completely dried up. Millard and Scott (1954) and Weil (1974) both stress the importance of this seasonal salinity gradient in limiting the faunal abundance and occurrence in the upper reaches of the Diep River estuary and head of Milnerton Lagoon. However, since the establishment of the channel along the east bank of Rietvlei in 1991/92, the estuary has become increasingly fresh water dominated (Murray *et al.* 2009; Jackson *et al*. 2008; Retief 2011). From our results it is clear that Milnerton Lagoon is infact currently fresh water dominated, with a salinity value of less than 15 ppt recorded at the Milnerton Bridge for the summer and winter period (Fig. 8). This can have massive implications for the fauna residing within the entire estuary system.

Faunistic changes

Sand prawns

Khanyile (2012) states that “the distribution of many animals in estuaries can be correlated with salinity gradients” also that salinity is one of the main determinates, affecting estuarine faunal distribution. This is clearly evident once you begin comparing how the sand prawn (*Callichirus kraussi*) abundances have changed over a 16 year period in the Milnerton Lagoon. Using the study done by Clark (1998) and this study (2014), it is clear that the sand prawn population has declined substantially. The estimated standing stock of sand prawns in Milnerton Lagoon is currently calculated at just over 12 million, whereas Clark (1998) determined the standing stock at approximately 40 million. Clark (1998) also recorded sand prawns up until 2.2 km from the mouth of Milnerton Lagoon, whereas from our study we found that the sand prawn distribution ended 1.6 km from the mouth. Additionally, it was determined that 93% of the total sand prawn population is currently vulnerable to bait collecting activities as all bait collecting activities are currently confined within the region between the mouth and 1000 m upstream. Weil (1974) also made some interesting observations with regard to the sand prawn distribution in the lagoon. He estimated the highest sand prawn concentrations as being near the mouth, just behind the old weir, and continuing just beyond Milnerton High School during the summer period (Weil 1974).

From these results, it is clear that sand prawn abundance and distribution within Milnerton Lagoon has undergone a massive decline. As already briefly mentioned above, salinity may be the causing factor behind this observed decline. *Callichirus kraussi* are euryhaline species, tolerating salinities between 1-65 ppt (Khanyile 2012). This wide salinity tolerance agrees with the wide distribution of adult *C. kraussi* in the lagoon, for example, salinity values measured by Weil (1974) in the summer period at Milnerton High School were close to 70 ppt (Fig. 8). However, the eggs and larval prawn stages are more sensitive to low salinities than the adult stages, as they require greater than 20 ppt in order to survive and complete their development within the parental burrow (Forbes 1978; Clark 1998; Khanyile 2012). This could explain why *C. kraussi* currently only occurs 1.6 km up the lagoon, ending near the small island just past the old wooden bridge (salinity values at the bridge were found to be less than 20 ppt during winter and summer for 2014 (Fig. 8)). Jackson *et al.* (2011) suggests that an alteration of the current salinity regime may become necessary in the future, in order for *C. kraussi* to reestablish in areas to which it previously occupied.

Another possible contributing factor behind the observed *C. kraussi* decline could be the actual physical disturbance imposed on the soft sediments of the lagoon through bait collecting. Prawn harvesting has been shown to create a number of detrimental impacts on the surrounding physical environment and on other biota, either through physical disturbance or by reducing the ecosystem services provided by burrowing prawn species (Clark 1998; Pillay and Branch 2011). Prawns are most commonly harvested by the use of hand-held prawn pumps, operated by sucking up a core of sediment, which is then examined for prawns (Clark 1998). This harvesting action combined with the harvester trampling over the soft lagoon sediments, causes prawn burrows' to collapse, compacts sediments and results in the burial and suffocation of numerous organisms (Clark 1998; Pillay and Branch 2011). Experiments carried out by Wynberg and Branch (1997) has shown that sediments from which *C. kraussi* had been removed became less porous and more compact, ultimately leading to sediment anoxia. Wynberg and Branch (1994) also showed that the physical disturbance associated with bait collecting can depress co-occurring invertebrate communities such as nematodes, copepods and juvenile polychaetes. A study determining the extent to which the prawn population is harvested and the potential consequences of this is required, in order to determine whether prawn harvesting at Milnerton Lagoon is a contributing factor leading to the noticeable decline in *C. kraussi* numbers and the faunal community.

Sand prawns as ecosystem engineers

C. kraussi has been classed as one of the most important ecosystem engineers in marine soft sediments, whereby their efforts govern a multitude of ecological processes. This ultimately enables a wide variety of organismal communities to colonise the sediment, which together with prawns constitute an important food source for many bird and fish species (Clark 1998; Pillay and Branch 2011). Their burrowing activities turn over vast quantities of sediment, which has been found to reduce bacterial colonization on the sediment surface, as well as oxygenate sediments down to sometimes greater than a meter (Clark 1998; Pillay and Branch 2011).

The sand prawn (*Callichirus kraussi*) clearly plays a highly important role within the Diep River estuary and the impacts brought on from its swift decline are evident when looking at the change in the abundance and type of infauna and epifauna from the first study done by Millard and Scott (1954) till now (2014). The altered salinity regime brought on by the discharge of sewage effluent into the estuary, combined with the physical disturbance from bait harvesting; may explain the current distribution and abundance of *C. kraussi* within Milnerton Lagoon. Clark (1998) suggested introducing a closed off season or period within the year or otherwise permanently closing off certain areas of the lagoon may become necessary in order for *C. kraussi* to re-establish in areas to which it previously occupied. I believe we have reached the point where serious management protocols are currently needed in order to rehabilitate this estuarine system, otherwise things will continue to become further degraded till a point where any recreational activity within the lagoon will be prohibited. Clark (1998) also suggested enforcing certain gear restrictions on bait collectors. I do not believe this is a viable option as Wynberg and Branch (1997) have shown through experiments that harvesters trampling on the soft sediment and the removal of prawns coupled with trampling have the same detrimental impact on sand prawn populations and surrounding fauna. The only viable option in my opinion would therefore be to close off the estuary for at least part of the year, preferably during the main breeding season from May-August. Additionally, the salinity regime for the estuary should be altered so that for a proportion of the year, the lagoon mouth is closed off. However, with the current pollution state of the estuary, this may be quite challenging to pull off without bringing about a ripple of other consequences.

Polychaetes

Polychaetes are known as the most tolerant taxon to low oxygen and are dominantly found in oxygen minimum zones (Mendez 2007). Many polychaetes are important descriptors of environmental conditions as they are generally the initial macrobenthic colonists after a disturbance and many inhabit highly polluted regions (Sarkar *et al.* 2005). Sarkar *et al.* (2005) showed that highly eroded and resuspended sediments have a greater penetration depth for burrowing organisms, thus favouring the settlement of a greater variety and number of burrowing polychaetes. One such polychaete is the rare or opportunistic *Ceratonereis* sp., which showed to utilize the unstable substratum (Sarkar *et al.* 2005). The Nereid polychaete (*Ceratonereis erythraeensis*) was found in highest abundance at the Milnerton Bridge in our study. Bait collecting activities occur most frequently near and at the Milnerton Bridge (Clark 1998), thus disturbing and resuspending the sediment in this region. This characteristic of *Ceratonereis* sp. could therefore be used to account for its recent addition to the list of species found within Milnerton Lagoon.

The opportunistic polychaete- *Capitella capitata* was found in relatively high abundances in all three studies. *Capitella capitata,* is known world-wide as only occurring in heavily polluted areas (Tsutsumi 1987) and is therefore regarded as a highly useful indicator of potential degradation by human activities (Sarkar *et al.* 2005). Tsutsumi (1987) analysed the population dynamics of *Capitella capitata* in an organically polluted cove in Japan, they found that *C. capitata* requires large amounts of organic matter to thrive and reach sexual maturity. This physiological requirement means that *C. capitata* populations may be exclusively found in heavily polluted areas. The absence of this genus or rapid decline of *C. capitata* populations in benthic regions going through recovery processes following the regression of pollution could make *Capitella* sp. highly useful environmental indicators. Pearson and Rosenberg (1978) postulated that a typical community response to stress is a reduction in the number of species, increase in total abundance of opportunistic species and a corresponding reduction in diversity. I believe this is what we are currently seeing as occurring within the Diep River estuary.

Fish

Millard and Scott (1954) report the thin lip grey mullet, white steenbras and white stumpnose as the most common fish found within the lagoon, whereas Weil (1974) found that the estuarine round-herring had the highest abundance within the lagoon. Today, you would find the estuarine round-herring (*Gilchristella aestrius*), harder (*Liza richardsonii*) and the mosquito fish (*Gambusia affinis*) as the most abundant fish species within the lagoon. Retief (2011) and *Jackson et al.* (2008) suggest that the low water quality combined with high ammonia concentrations experienced at the lagoon through malfunctions in the WWTW, have caused important benthic organisms, such as *Callichirus kraussi*, and other invertebrate species to undergo a massive decline, which are important food sources for fish. As a consequence of this, important line-fish species within the Diep River estuary have shown a great decline, resulting in the fish assemblage being dominated by species such as *Liza richardsonii* and the alien invasive *Gambusia affinis.*

Alien invasive species

Ficopomatus enigmatica

The reef-building polychaete, *Ficopomatus enigmatica*, is a fast-growing, highly invasive species that acts as an ecosystem engineer, capable of modifying its habitat physically, chemically and biologically (Schwindt *et al.* 2001; Heiman *et al.* 2008; McQuaid and Griffiths 2014). This species originates from Australia and prefers nutrient rich waters, can survive in a large range of temperatures and salinities and is extremely tolerant to stress (McQuaid 2013). Its large reefs consist of a dense network of calcareous tubes and originate when the planktonic larvae settle on hard substrata, such as rocks, reeds and even hardened sediments (Millard and Scott 1954; Weil 1974; McQuaid 2013). Weil (1974) noted this species as the most successful colonizer within Milnerton Lagoon, recorded as highly abundant at stations 1 and 2, extending all the way until station 5. The development of concrete walls along the banks of the Diep River estuary and the construction of four bridges from 1904 till 1985 across the Milnerton Lagoon possibly facilitated the recruitment and expansion of this highly invasive species within the estuary, as shown by the recent work by McQuaid and Griffiths (2014) and McQuaid (2013) on the Zandvlei Estuary in Cape Town, South Africa. To date, no studies have yet quantified the spread of this highly invasive species within the Diep River estuary.

Ficopomatus enigmatica as an ecosystem engineer

As already mentioned, *F. enigmatica* is a highly influential ecosystem engineer. The impact that this species has on native communities and the surrounding environment is highly complex and includes both positive and negative effects (Schwindt *et al.* 2001; Heiman *et al.* 2008; McQuaid and Griffiths 2014). *F. enigmatica* provides a new, structurally complex heterogeneous habitat in this muddy ecosystem (Schwindt *et al.* 2001; McQuaid and Griffiths 2014). The reefs enhance invertebrate recruitment and survival, by providing shelter, food and substratum for both native and non-native species (Schwindt *et al.* 2001; Heiman *et al.* 2008; Heiman and Micheli 2010; McQuaid and Griffiths 2014). Affected organisms include polychaetes, amphipods, gastropods and juvenile crabs (Heiman and Micheli 2010; McQuaid and Griffiths 2014). McQuaid (2013) found a variety of infaunal species associated with *F. enigmatica.* Some of these species include *Afrochiltonia capensis, Melita zeylanica, Hymenosoma orbiculare*, the estuarine snail *Tomichia ventricosa;* a nematode species, the nymphs of the damselfly *Ischnura senegalensis* and the larvae and pupae of a *Chironomus* species. McQuaid and Griffiths (2014) also found a greater abundance of the crab *Hymenosoma orbiculare* associated with *F. enigmatica* reefs. The findings from these two studies support our observations, as *Melita zeylanica, Hymenosoma orbiculare* and *Ischnura senegalensis* nymphs were found in relatively high abundance in all three studies, where *F. enigmatica* reefs were established. A study quantifying the association of these observed species with the *F. enigmatica* reefs is required in order to make more meaningful conclusions.

Besides providing habitat, food and shelter for native and non-native species, *F. enigmatica* has also been shown to play a highly important role in maintaining water quality in moderately polluted systems (Davies *et al.* 1989). Davies *et al.* (1989) showed that *F. enigmatica* provides a fundamental filtration role in polluted-brackish water systems, by improving water quality-reducing particle loads through its feeding activities. However, this may also limit the food available to other, native infaunal filter feeders (Heiman and Micheli 2010). Additionally, faecal matter has been found to accumulate under and around *F. enigmatica* reefs, which could possibly lead to hypoxic or anoxic conditions within surrounding sediments, thereby decreasing local infaunal abundances (Heiman and Micheli 2010). The high abundance of detritivores observed by Weil (1974) and in this study, may therefore be the result of the enhanced local availability of organic matter under and around these artificial reefs (Heiman *et al.* 2008; Heiman and Micheli 2010). The areas surrounding these reefs also limit the space available for burrowing organisms (Wilson 1991). A study by Heiman and Micheli (2010) showed this quite nicely, where native and non-native infaunal species were found in lower abundance under and adjacent (5 cm away) to the reefs. This indicates that the reefs may therefore negatively impact rather than facilitate infaunal assemblages (Heiman and Micheli 2010). Heiman *et al.* (2008) suggests that the eradication of this strongly interacting invasive species may result in the control of a collection of other non-native species. Whereas, Davies *et al.* (1989) suggests that the eradication of this species in moderately polluted systems should not be considered as even an option, in view of its filtration role. More research on this species is therefore required in order to conclusively state the impact that it has on its surrounding environment and on native communities and then further, the management decisions that should follow.

Gambusia affinis

The alien invasive *Gambusia affinis* is one of the most widely introduced species on the planet, and is recognised as being among the worst invasive fish species worldwide (Howell *et al.* 2013). This species was first introduced into South Africa in 1936 for mosquito control and is now well established in freshwater ecosystems across southern Africa (Howell *et al.* 2013). While humans have regarded *G. affinis* as beneficial because of their control on mosquitoes, *G. affinis* is likely to have a variety of deleterious impacts including competition with native fish and frogs, alterations of invertebrate and vertebrate communities through predation, habitat alteration and introduction of fish diseases (Howell *et al.* 2013). Invasive fishes such as *G. affinis* are largely responsible for habitat degradation and species loss (Howell *et al.* 2013).

Conclusion

In the last 200 years, the Diep River estuary has gone through a significant amount of modifications. Activities in the Diep River catchment, together with the intensive urban development in the areas adjacent to the estuary have resulted in massive changes to biodiversity, altered flow and salinity regimes, deterioration in water quality and a frightening increase in non-indigenous species introductions. Earlier studies on this system report the Diep River estuary as relatively unpolluted in terms of nutrients and trace metals, with a high abundance and diversity of fish and invertebrate species. Current evidence suggests the situation has deteriorated strikingly since then, with unacceptably high microbial levels being recorded in the lagoon and a marked decrease in the number and abundance of invertebrate species. This decrease is clearly shown by observing the massive change in sand prawn (*Callichirus kraussi*) abundance and distribution in the lagoon, in a relatively short time period of only 16 years. These changes and disturbances have inevitably resulted in the expansion and new introduction of exotic and invasive species such as the European beach hopper (*Orchestia gammarella*), the highly invasive mosquito fish (*Gambusia affinis*) and the invasive reef-building worm (*Ficopomatus enigmatica*). Serious action addressing these problems needs to be implemented before this highly valued system is put under further stress and degradation. Further development within and around the estuary needs to be prevented.

Major consideration needs to be given to reducing some of the pollution sources. Additionally, a salinity regime and new bait collecting restrictions that promotes the reestablishment of the highly important sand prawn needs to be enforced with great urgency. A regular monitoring of the infauna and epifauna populations for this system also needs to be established, in order to obtain a clear picture of the faunistic distribution and changes occurring within this highly dynamic environment.

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